PERSPECTIVE THERMAL CONTROL SYSTEMS (TCS) OF SPACECRAFTS ON THE BASIS OF TWO-PHASE MECHANICAL PUMPING LOOPS

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Abstract

The problems of efficiency of use of two-phase loops (TPL) in TCS of perspective spacecrafts and backlog created for their introduction are considered in this article. Such types of TCS have not been used on spacecrafts yet, in spite of their advantages. It is connected with new approaches at their creation, with absence of experience of operation in 0-g conditions, with use of new heat-transport elements, new methods of terrestrial testing, new methods of calculation. It is shown in the work, that these systems are perspective; they give an essential prize in weight of TCS, in an energy consumption, in mass and dimensional characteristics. These parameters depend on specific requirements to TCS of spacecrafts and they can achieve rather significant sizes. For instance, use of a two-phase ammonia loop (as a thermal bus) in the 30 KW Centralized Heat Transfer System (in its final configuration) for Russian Segment (RS) of the international space station (ISS) gives a weight prize of several hundreds kg and an energy consumption prize of thousands of watts. The elements of this system have been developed and they have passed a stage of terrestrial tests on a created specialized investigation base. The results have been confirmed by flight tests of functional analog of such system. The calculations of various TPL schemes for perspective high-power (over 5 KW) geostationary communication spacecrafts have shown, that weight prize achieves tens kg, and an energy consumption prize achieves tens watts in a comparison with conventional single-phase TCS.

KEYWORDS

The two-phase thermal control system, spacecrafts, ammonia, terrestrial tests.

INTRODUCTION

An increase of efficiency of spacecrafts is inseparably linked with requirements of improving of auxiliary systems parameters, to which spacecraft TCS concerns. The heat of phase transition is much more than thermal capacity by its specific value. It means that transition from convective TCS to two-phase TCS will bring a weight prize (smaller diameter of pipelines, reinforcement, cool agent mass), an energy consumption prize (smaller power of the pump) and will allow to supply a higher thermostability of spacecraft elements [1]. Such systems successfully work on the Earth in nuclear and other industries, household activities for a long time. However, weightlessness conditions insert large uncertainty to TCS TPL activity, where the use of cool agent pumping by a mechanical pump is necessary.

Different types of heat pipes, that use capillary forces and provide a heat transfer by phase transition, have found broad application in spacecrafts TCS; they have already shown their efficiency, especially on small power (order of 2-3 KW) spacecrafts that have small overall dimensions

But high-power and large-dimensional spacecrafts TCS construction on a base of heat pipes only is not effective. Heat pipes have small adjustment range, they have rather small powers (from several watts up to some hundreds watts), the modern and perspective capillary structures do not allow to provide large distance of heat transfer (tens meters). Heat reception zones have, as a rule, cylindrical form and limited surfaces of heat exchange that is not always desirable for large number of devices and equipment. It results in decrease of efficiency of heat pipes, especially at their sequential connection. Several degrees are lost on each connection and this results first of all in increase of overall dimensions (and a weight) of a radiator. In these cases the systems with mechanical pumping of a cool agent are attractive. It also use heat pipes in a radiator, but it have not disadvantages of heat pipes listed above. However, new problems arise: hydrodynamics and heat exchange calculation of two-phase flows in ramified systems in weightlessness conditions, pressure regulation in a loop, provision of cavity-free activity of the pump, reliability of a system etc. The estimated calculations show high efficiency of two-phase systems and expediency of their application on perspective high-power spacecrafts.

SELECTION TPL OF TCS.

Since 1970 TCS TPL are actively studied in some country [1]. In 1990 years study of such system for a space station is begun in RSC "Energia", together with a number branch-wise (Keldysh Research Center, TSNIIMASH) and educational (MGTU, KhAI, MAI) institutes. A decision on construction RS ISS has given a large impulse to this work. The most effective cool agent for such systems is water-free ammonia (particularly clean ammonia – the same ammonia that for ammonia heat pipes). A principle scheme of such TCS is shown on figure 1.

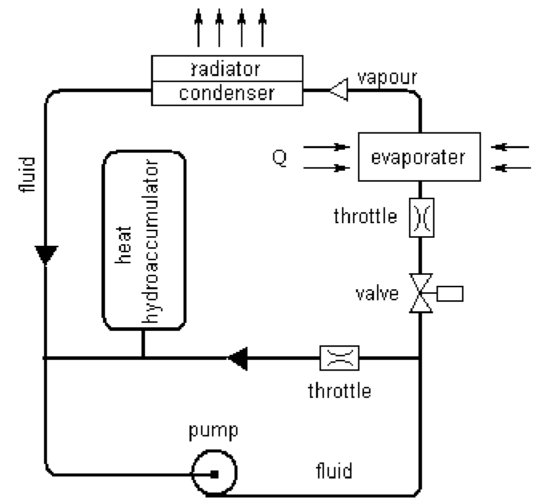

Figure 1. A principal scheme of spacecraft TCS TPL

Two-phase TCS of RS ISS provides thermal stabilization of equipment and separate modules of spacecrafts and also comfortable conditions for activity of crew (temperature in compartments is about +20°C). The efficiency of TCS activity depends on a pressure level set-up in a thermal hydroaccumulator, on selection of a bypass line parameters for stable activity of a pump, throttles, control units, on the TPL TCS scheme as a whole. A block diagram for the RS ISS is shown on figure 2.

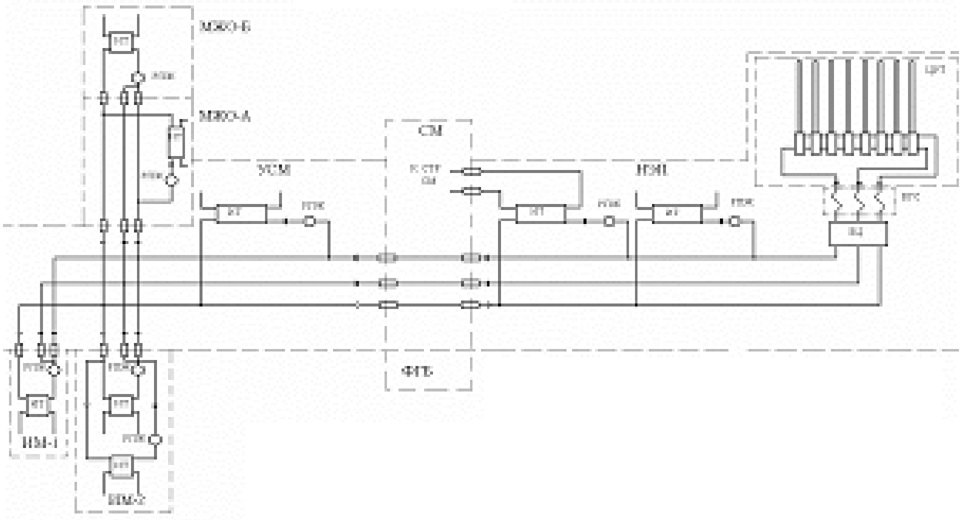

Figure 2. The block diagram of the centralized heat rejection system (CHRS)

The comparative analysis of two-phase TCS with a single-phase CTP, similar to the system that had been used before on the space station "MIR" was conducted with use of developed TCS mathematical models and of thermal mode of ISS as a whole. The mass-power parameters of the scheme in a comparison with single-phase TCS are given in Table 1.

Table 1

Comparative characteristics of two-phase and single-phase CHRS of RS ISS with power about 30 KW

Performance	Single-phase CHRS	Two-phase CHRS
Radiation heat exchanger square, m^2	196	150
Cool agent	ПМС–1,5	particularly clean ammonia
Quantity of cool agent, sm^3/sek	2000	150
Energy consumption, W	2000	170
Cool agent volume, l	500	70
Pipes diameters, mm	30–50	10–18
Mass, kg	4140	2780

For automatic spacecrafts, that have enough broad range of temperatures of various elements, it is more profitable to use the hybrid scheme with a heat removal to single-phase and two-phase flows of the cool agent (this type of scheme has several levels of temperature stabilization, shorter economizer tracts for extended evaporators, temperature optimization of radiating coolers). An example of such scheme is given on figure 3.

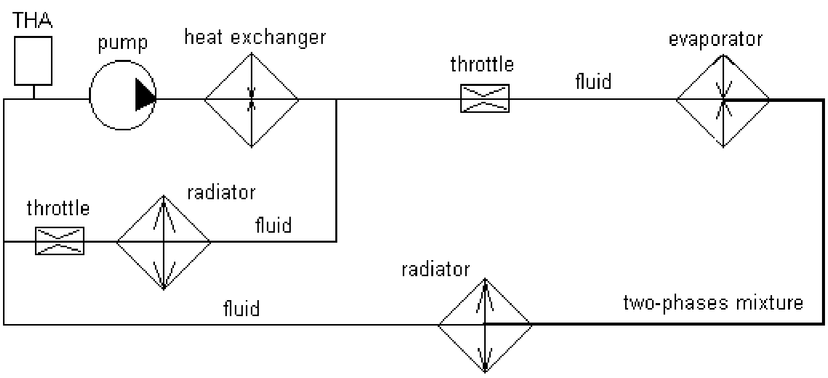

Figure 3. The hybrid scheme of TCS

Calculations of energy and mass characteristics of TPL TCS for communication satellites are shown on figures 4 and 5. It is visible, that with growth of power, a TCS TPL mass economy increases (in a comparison with single-phase TCS) practically linearly in the considered range of parameters and achieves rather large values.

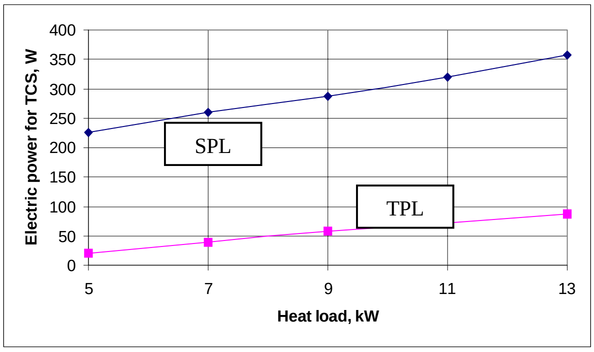

Figure 4

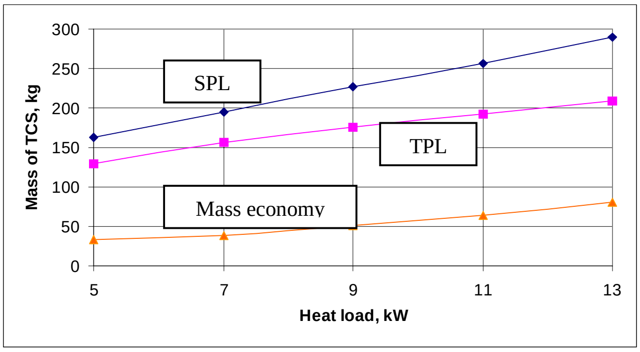

Figure 5

An energy consumption and mass economy gives also a considerable economical profit. Cost evaluations of introduction of such systems are given in figures 6 and 7.

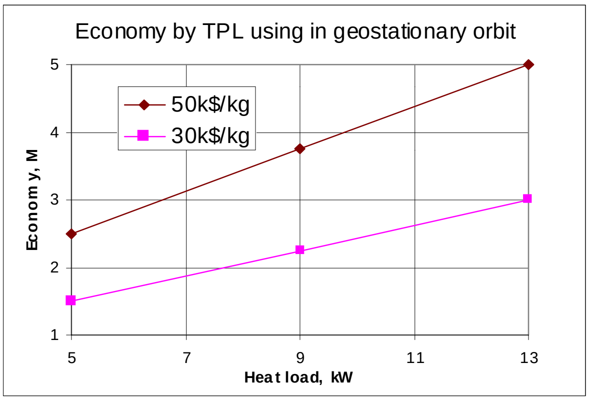

Figure 6

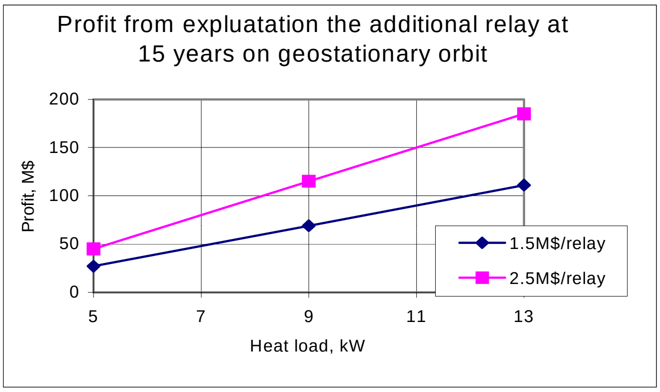

Figure 7

The prize is achieved either due to reduced mass of a spacecraft or at the same mass of spacecraft but at the expense of the installation of additional commercial communication channels, and makes $ millions. Thus payback time of the spacecraft also are reduced.

ELEMENTS FOR TPL OF TCS

There are very big difference between elements TPL of TCS and elements of single-phase TCS. It is rather a difficult task to provide the most full transition of a cool agent from a liquid phase to a gaseous one in weightlessness conditions. The factors of heat exchange and in conditions of normal gravitation are determined on empirical relations, which, as a rule, are found for a particular kind of heat exchangers and particular heat-carriers. For conditions of weightlessness such data are absent. Using earlier accumulated positive experience on creation of evaporators of an opened type, the ablative heat exchangers for TPL are expedient for creating labyrinth-slotted, auger of types, with special turbulator or special profile of a heat-exchange surface with grooves as for HP. Thus the centrifugal, capillary forces are used, at the expense of which the radiator surface remains moistened. On Figure.8 and 9 the versions of evaporators of such type are shown.

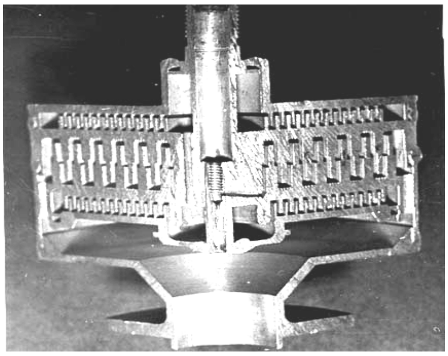

Figure 8 Radial - labyrinth evaporator

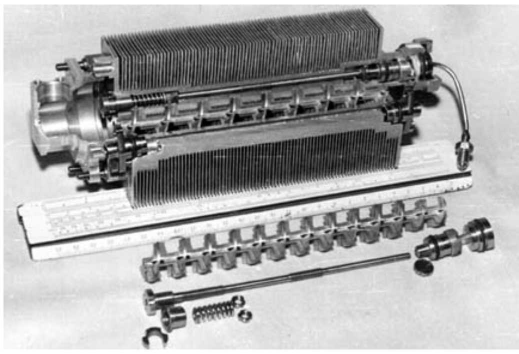

Figure 9   Auger evaporator

At weightlessness when at the small charges (about 1g/s ammonia at 1kW of heat load) and at appropriate heat-flux density (about 50кВт on sq. meter) the process of boiling in large volume should be realized. It has proved to be true both at ground and flying tests. On ground evaporator work practically irrespective of a direction of force of weight, in flying experiments the steam quality on output was not reduced of the below given size (80 %).

The condensers were developed on the basis of capillary structures on heat-exchange surface (see fig. 10).

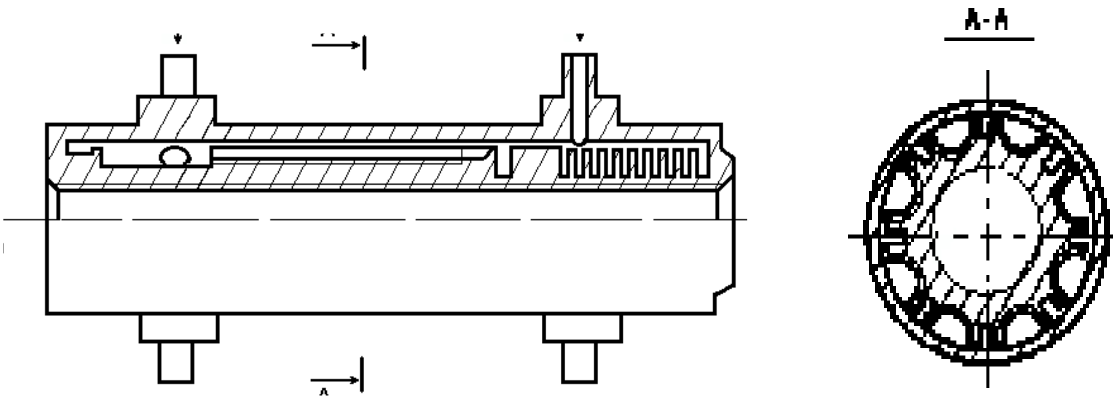

Figure 10 The condenser for RS ISS

Such design also has confirmed the serviceability in ground and in flying experiments. At sink of heat load from a radiator on a basis heat pipes, the zone of evaporation of a heat pipe (HP) is placed inside the condenser in the central channel and has thermal connection with it of the necessary area.

Throttle can be represented by sets of washers with calibrated non-coaxial by apertures, capillary pipes etc. The hydroaccumulator is necessary, basically, for adjustment of saturated pressure in TPL and maintenance of a required temperature level [2]. Its design should have the capillary - intaking device and thermal regulator (for example heater with HP).

TEST BENCH FOR IMPROVEMENT AMMONIA TPL.

For improvement of elements TPL RS ISS and loop as a whole, for realization of research works in this direction the base was created specialized laboratory. The workplaces for improvement evaporators, condensers, throttles, thermal hydroaccumulator (THA), pump, preparation of the heat-carrier, devise of infill TPL by ammonia of workplaces were created. Besides the appropriate technological systems - vacuum, heat load and sink systems, complex on management of experiments and measurement are created too. The ammoniac complex was created for improvement TPL on capacity up to 30кВт. In a fig. 11 the general view of the stand with TPL of RS ISS is given.

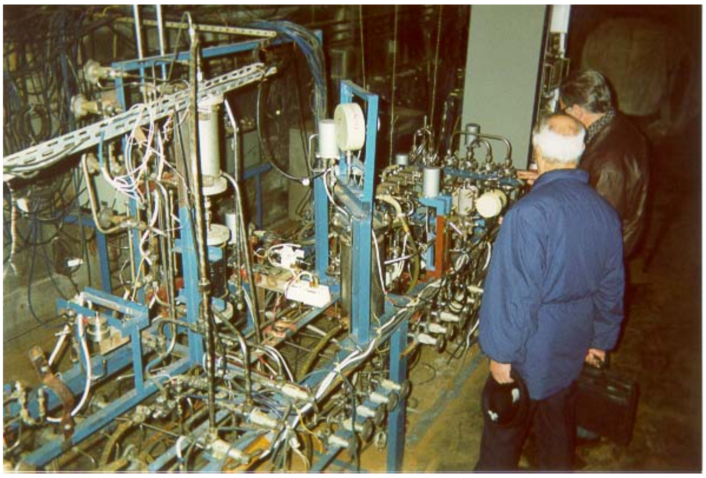

Figure 11. General view of the test bench.

The basic experiments will be carried out in a horizontal plane, but on independent workplaces elements TPL (evaporators, condensers, hydroaccumulator) can be established in a various situation concerning a direction of force of weight. The results of work of the hydroaccumulator are given in a fig. 12. If temperature of envelope of THA is maintenance with accuracy $\pm 1^0$C the pressure in THA varies in limits ± 0.024MPa and the varies pressure in loop is the same.

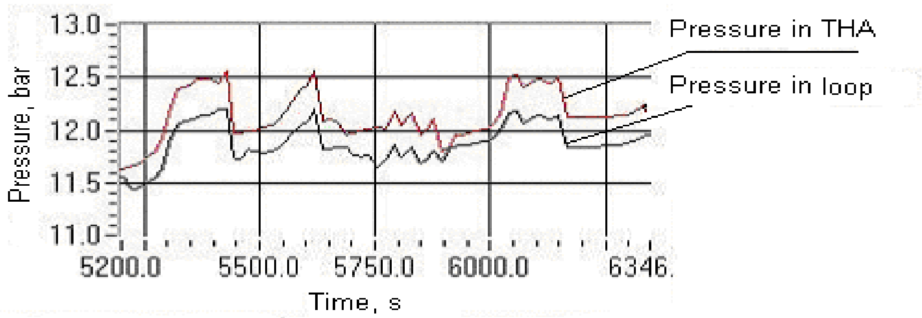

Figure 12

The special attention was given to improvement of the pump for ammonia. The pressure-consumption characteristics, size cavitations stock were received. Pump is shown in a fig. 13.

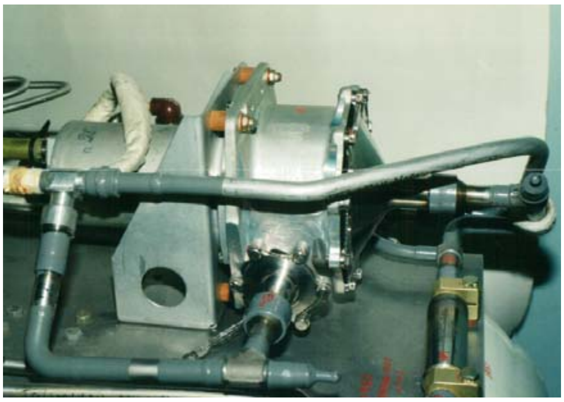

Figure 13. The electric pump unit (ammoniac pump)

In experiment the technique of a way out of the pump from a cavitations mode is fulfilled. This method based on decrease of heat load and increase of pressure in the loop with the help of the hydroaccumulator heater. The test bench for purification of technical ammonia up to a level of especially pure ammonia also is created; the system of selection of assay and analysis of ammonia on a microimpurity is fulfilled. On base of Fourier-spectrometer of the high sanction the technique and appropriate equipment for realization of the operative analysis of microimpurity of water (up to 10^{-4} %) in ammonia is developed [3,4]. The technique of clearing of a contour from microimpurity, technique final infilling etc. were developed.

PREPARATION AND REALIZATION OF FLYING EXPERIMENT WITH TPL AS ANALOGUE TCS FOR RS ISS.

For a final confirmation of serviceability TPL in РКК "Energy" was designed flying analogue (experimental plant - LEU) TCS of RS ISS. The circuit LEU (fig. 14) on logic of construction is similar TCS of RS ISS.

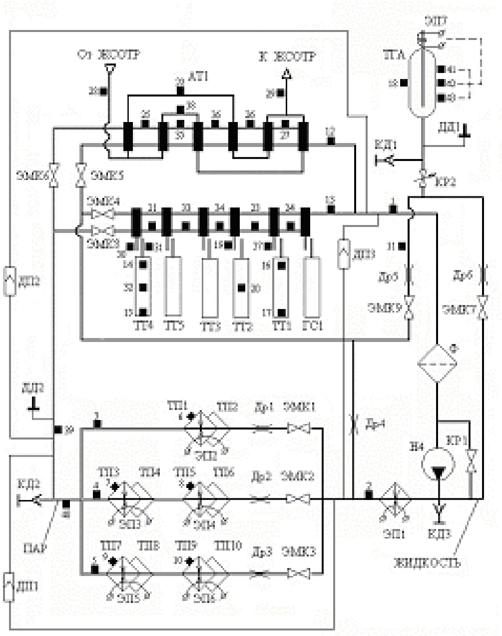

Figure 14

Figure 15

Maximum heat load in LEU is 1kW. LEU was placed on spacecraft "Progress" and in structure of station "Mir". In 1999 on it were carried out the numerous experiments in conditions of weightlessness. For ground support of flying experiment was made the appropriate sample LEU. Its kind on the test bed is shown in a fig. 15.

In a fig. 16 the pump block is shown separately.

Figure 16. The pump block LEU.

On the ground model on independent workplaces were carried out the tests and improvement of separate elements LEU (evaporators, condensers, throttles, hydroaccumulator). On a ground sample LEU the circuit as a whole was fulfilled, the modes of operations, installation sites of gauges, their range of work and type of gauges are specified. The verification of mathematical model of account TPL is carried out. The special attention is given to washing and infill TPL by ammonia. Ammonia is very aggressive with regard to copper and it is danger for electric devises. For infill TPL was design special test plant as ammoniac filler, in which the washing, infill of ammonia, selection of tests of ammonia for the analysis of micro-impurity was carried out. The filler is shown in a fig. 17.

Figure 17. The filler of ammoniac.

On Bayconur this filler was apply for filling ammonia in LEU. Flying experiments have shown serviceability of a loop with start-up in single-phase and two-phase modes. It was stabile work of all system at transition from one mode on another at the expense of change of transmitted heat load, at change of a temperature level of work. The sure output from a cavities mode of the pump was carry out. The received results correspond to the technical requirements of this two-phase ammoniac loop. The results of ground experiments will well be coordinated to the data of flying experiments.

In a fig. 18 and 19 some results of flying experiments with LEU are shown. On Figure 18 it is visible, as after inclusion of an electrical heater on evaporates by capacity 170W temperature it rises up to 32^0C, the liquid ammonia evaporates and with some delay begins to be condensed in the condenser and its temperature also rises up to 32^0C. To system works in an equilibrium mode.

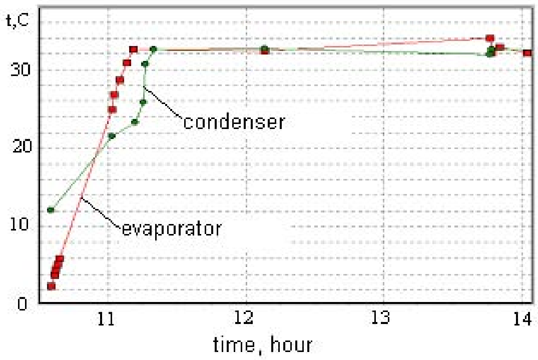

Figure 18

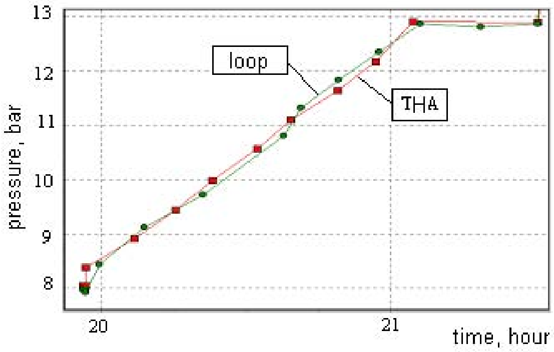

Figure 19

On Figure 19 other experience is given, from which it is visible, as after inclusion of an electrical heater on THA, the pressure in it grows up to 1.3MPa, simultaneously thus the pressure of saturation in a loop also grows up to 1.3MPa. Thus, the management of pressure of saturation in a loop by regulation of capacity of a heater TГA is carried out.

CONCLUSION

As a result of work is shown:

- Serviceability of two-phase loop of thermal control systems of space vehicles;
- Correctness of the incorporated technical decisions at designing elements TPL and system as a whole;
- Opportunity of ground improvement TPL on the created ammoniac complex is shown;
- High efficiency (on weight, dimensions, electric power) such systems for perspective, large-sized, with the increased installed power per employee spacecrafts;
- High economic parameters from introduction of such systems on perspective spacecrafts in comparison by single-phase system.

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